U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-301 255

Sediment Characteristics of the 2800 Meter Altantic Nuclear Waste Disposal Site: Radionuclide Retention Potential

(U.S.) Office of Radiation Programs, Washington, DC

Sep 79

United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington DC 20460

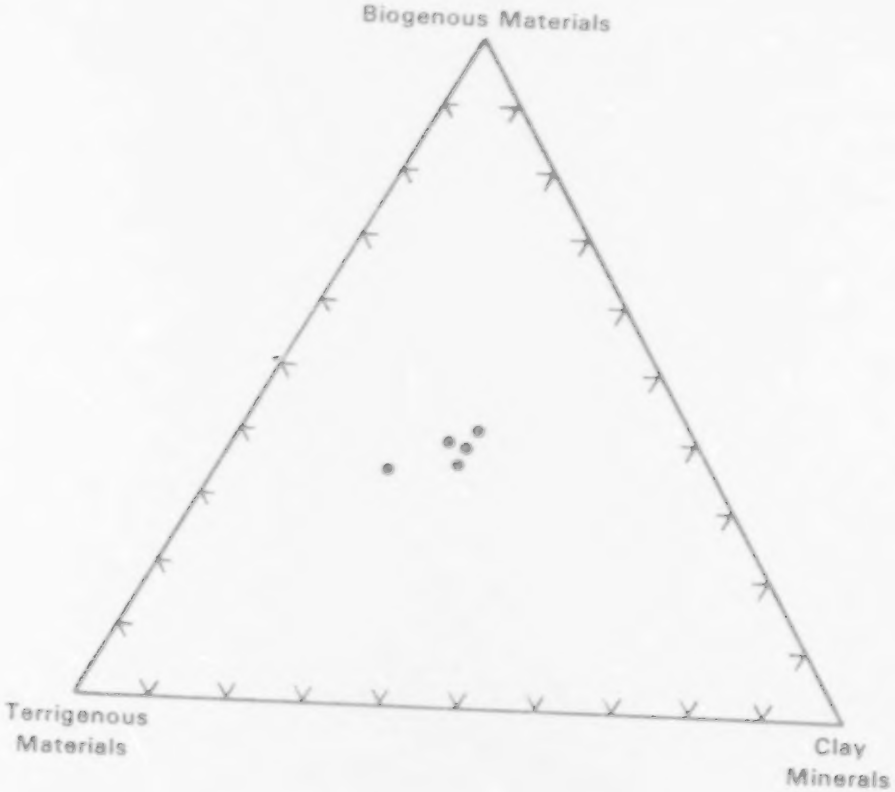
Technical Note
ORP/TAD-79-10
September 1979

Radiation

PB 301255

EPA

Sediment Characteristics of the 2800 Meter Atlantic Nuclear Waste Disposal Site: Radionuclide Retention Potential



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC INFORMATION

PB-301 255

Sediment Characteristics of the 2800 Meter Altantic Nuclear Waste Disposal Site: Radionuclide Retention Potential.

Sep 79
James Neiheisel.

PERFORMER: Office of Radiation Programs, Washington, DC. Technology Assessment Div.
ORD/TAD-79/10

Prepared in cooperation with Corps of Engineers, Washington, DC.
The sediments of the abandoned 2800 meter Atlantic nuclear waste dumpsite have been analysed for texture mineral composition, physical properties, cation exhange capacity, and factors effecting sediment deposition, as part of an extensive program by the Environmental Protection Agency to evaluate ocean disposal as an alternative nuclear waste disposal method. The sediments physical and chemical properties are evaluated in the light of the geologic setting for their potential role in retarding radionuclide leachate migration from the waste drums to the water column.
KEYWORDS: *Radioactive waste facilities, *Marine disposal.

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A03/MF A01

TECHNICAL NOTE
ORP/TAD-79-10

SEDIMENT CHARACTERISTICS OF THE 2800 METER ATLANTIC NUCLEAR WASTE DISPOSAL SITE: RADIONUCLIDE RETENTION POTENTIAL

by

James Neiheisel
Technology Assessment Division
Office of Radiation Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

September 1979

This report was prepared with the technical support of the United States Army, Corps of Engineers under Interagency Agreement EPA-78-H0152

Project Officer
Robert S. Dyer

Radiation Source Analysis Branch
Technology Assessment Division
Office of Radiation Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

EPA REVIEW NOTICE

This report has been reviewed by the Office of Radiation Programs, U.S. Environmental Protection Agency (EPA) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the EPA. Neither the United States nor the EPA makes any warranty, expressed or implied, or assumes any legal liability or responsibility of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

EPA TECHNICAL PUBLICATIONS

Publications of the Environmental Protection Agency's (EPA) Office of Radiation Programs (ORP) are available in paper copy, as long as the EPA/ORP supply is available, or from the National Technical Information Service (NTIS), Springfield, VA 22161.

The following reports are part of the EPA/ORP 1976 Ocean Disposal Report Series:

ORP/TAD-79-1 Materials for Containment of Low-Level Nuclear Waste in the Deep Ocean

ORP/TAD-79-2 On Board Corrosion Analysis of a Recovered Drum from the Atlantic 2800 Meter Radioactive Waste Disposal Site

ORP/TAD-79-3 Analysis and Evaluation of a Radioactive Waste Package Retrieved from the Atlantic 2800 Meter Disposal Site

ORP/TAD-79-4 Reports of Infaunal Analyses Conducted on Biota Collected at the Atlantic 2800 Meter Radioactive Waste Disposal Site

ORP/TAD-79-5 Geologic Observations of the Atlantic 2800 Meter Radioactive Waste Dumpsite

ORP/TAD-79-6 Sediment Geochemistry of the 2800 Meter Atlantic Radioactive Waste Disposal Site

ORP/TAD-79-7 Ocean Current Measurements at the Atlantic 2800 Meter Radioactive Waste Disposal Site

ORP/TAD-79-8 Survey Coordination and Operations Report - EPA Atlantic 2800 Meter Radioactive Waste Disposal Site Survey

ORP/TAD-79-9 1976 Site Specific Survey of the Atlantic 2800 Meter Deepwater Radioactive Waste Dumpsite: Radiochemistry

ORP/TAD-79-10 Sediment Characteristics of the 2800 Meter Atlantic Nuclear Waste Disposal Site

TABLE OF CONTENTS

	Page
List of Tables and Figures	iv
Abstract	v
Introduction	1
Geological Setting	1
Sample Locations	3
Analytical Methods	3
Sediment Texture	4
Sedimentary Parameters	5
Physical Proporties	8
Sediment Composition	10
Biogenous Materials	10
Terrigenous Materials	16
Clay Minerals	16
Characteristics of Clay Minerals	19
Cation Exchange Capacity	21
Distribution Coefficient,(Kd), Considerations	21
Sediment Source Considerations	23
Sedimentation Processes Affecting Radionuclide Distribution in Sediment	25
Summary and Conclusions	26
Acknowledgements	27
Reference Cited	27

Preceding page blank

LIST OF TABLES AND FIGURES

Page

TABLES

1. Texture Physical Properties and Sedimentary Parameters of Sediment from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity.....6

2. Mineral Suite of Sand-Silt-Clay Size Fractions and Average Sediment Composition from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity.....9

3. Heavy Mineral Analysis of Sand-Size Sediment from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity...17

4. Clay Minerals of Clay-Size Fraction of Sediments from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity...18

5. Cation Exchange Capacity of Sediment from 2800 Meter Atlantic Nuclear Waste Disposal Site.....20

FIGURES

1. Sediment Sample Locations of 2800 Meter Atlantic Nuclear Waste Site and Vicinity taken in 1975 and 1976.....2

2. Triangular Textural Diagram of Sediment from the 2800 Meter Atlantic Nuclear Waste Disposal Site.....7

3. Photomicrograph of Sand-Size Fraction of Sediment from 2800 Meter Atlantic Nuclear Waste Disposal Site.....11

4. Scanning Electron Micrograph of Silt-Size Material from 2800 Meter Atlantic Nuclear Waste Disposal Site.....12

5. Scanning Electron Micrograph of Silt-Size Material from 2800 Meter Atlantic Nuclear Waste Disposal Site.....13

6. Scanning Electron Micrograph of Clay-Size Material from 2800 Meter Atlantic Nuclear Waste Disposal Site.....14

7. Scanning Electron Micrograph of Clay-Size Material from 2800 Meter Atlantic Nuclear Waste Disposal Site.....15

8. Direction of Longshore Currents Near Shore, Turbidity Flow Down the Submarine Canyons, and Predominant Bottom Flow in Vicinity of 2800 Meter Atlantic Waste Site.....24

ABSTRACT

Sediment Characteristics of the 2800 Meter
Atlantic Nuclear Waste Disposal Site:
Radionuclide Retention Potential

by
James Neiheisel

The sediments of the abandoned 2800 meter Atlantic nuclear waste dumpsite have been analyzed for texture mineral composition, physical properties, cation exchange capacity and factors effecting sediment deposition, as part of an extensive program by the Environmental Protection Agency to evaluate ocean disposal as an alternative nuclear waste disposal method. The sediments physical and chemical properties are evaluated in the light of the geologic setting for their potential role in retarding radionuclide leachate migration from the waste drums to the water column.

The sediments are relatively uniform silty clays and clayey silts comprised of approximately one-third biogenous carbonate materials, one-third terrigenous materials and one-third clay minerals. The biogenous materials in the sand and upper silt-size fraction are predominantly foraminifera with minor amounts of diatoms while coccoliths dominate the finer silt and clay size fractions. The terrigenous materials in the course sediment fractions are predominantly quartz and feldspar with minor amounts of mica, glauconite, and heavy minerals. Clay minerals, of the clay-size fraction, in order of abundance, include illite, kaolinite, chlorite and montmorillonite.

Relatively high cation exchange capacity in the sediment (15.2-25.4 meq/100g) is attributed to the clay minerals comprising approximately one-third of the sediment. Correspondingly high Kd values might also be expected as a result of sorption of radionuclides onto clay minerals with most favorable conditions related to pH, Eh, and other environmental factors. The biogenous fraction might also be expected to retain some strontium-90 by isomorphous substitution of this radionuclide for calcium.

Diagnostic heavy minerals in the sand-size fraction reflect the source areas as predominantly the adjacent continental shelf, and provide important clues concerning the mechanisms effecting transport and deposition of the sediment. Longshore currents along the coast funnel sediment into the Hudson Canyon and turbidity currents transport sediment down the submarine canyon; some of this sediment is advected in a southwesterly direction from the submarine canyon by contour currents for deposition along the continental rise. The net deposition at the waste site thus consists of the "rain" of biogenous microorganisms, the transport of sediment from the coastal and continental shelf area by turbidity currents via submarine canyons, and transport of sediment along the continental rise by prevailing contour currents.

The effectiveness of the sediment barrier relates to timely burial of the waste drum prior to leachate release from ruptured or corroded drums as well as freedom from "short circuiting" effects such as bioturbation or other mechanisms capable of providing migration pathways for the radionuclides.

Introduction

The Ocean Disposal Program of the Environmental Protection Agency is currently involved in investigating abandoned nuclear waste disposal sites in the Pacific and Atlantic Oceans. The condition of the 55 gallon steel waste drums deposited at these sites between 1950 and 1962 and their impact on the ocean environment is under extensive investigation. Information gained by field and laboratory investigations of the factors effecting the stability of the waste site will enable evaluation of ocean disposal as a potential alternative method to present land burial disposal methods. An evaluation of the ability of the sediment to act as a barrier to the migration of radionuclides leached from the waste form and the geological stability of the site will provide important data for considerations governing future ocean disposal.

At present, little is known about deep ocean sediment as regards its physical properties, mineral composition, or ability to effect sorption and retention of radionuclides. This laboratory investigation of sediment samples from the 2800 meter site reports on the geologic setting, sediment texture, physical properties, mineral composition, and chemical parameters of one of the major abandoned waste sites. Consideration is given to the potential ability of this sediment to act as a geochemical barrier in the sorption of radionuclides and preventing their migration from the disposal site. Site stability is evaluated in light of the sedimentological findings, including use of diagnostic heavy minerals to delineate source areas, as well as field observations of the hydrodynamic factors.

Geologic Setting

The 2800 meter Atlantic site, situated approximately 190 kilometers off the New Jersey coast, comprises an area of 256 km^2 centered at 38° 39'N and 72° 00' W. The bottom topography at this site is a smooth, gently sloping surface typical of the upper continental rise (Figure 1).

The Hudson Canyon, approximately 70 km northeast of the 2800 meter site, is the largest submarine canyon of the Atlantic continental shelf. Submarine canyons are believed to act as sediment traps that funnel terrigenous sediments down the slope as turbidity currents. Deltas on the abyssal plain at the foot of the Hudson Canyon have been described by Pratt (1) and other investigators as material transported via the thalweg of the canyon to this deposition site. Some of the sediment undoubtedly overflows the canyon or is resuspended from the submarine canyons by hydrodynamic agents and other mechanisms including biological activity. This sediment source as well as sediment transported by bottom contour currents and the biogenous materials of the marine environment constitute the materials available for deposition at the waste site.

Observations of the 2800 meter nuclear waste by the SRV Alvin during 1975 and 1976 by Rawson and Ryan (2) reveal that the site is carpeted by fine grained muds. Photographs of the steel drums reveal sediment plumes extending in a southwesterly direction; this reflects prevailing or strongest current flow from the northeast predominantly parallel to bottom topography. Current measurements from meters deployed during field operations in August and November 1976 indicate diurnally varying oscillatory currents up to 0.5 knots with strongest velocity flow in a southwesterly direction.

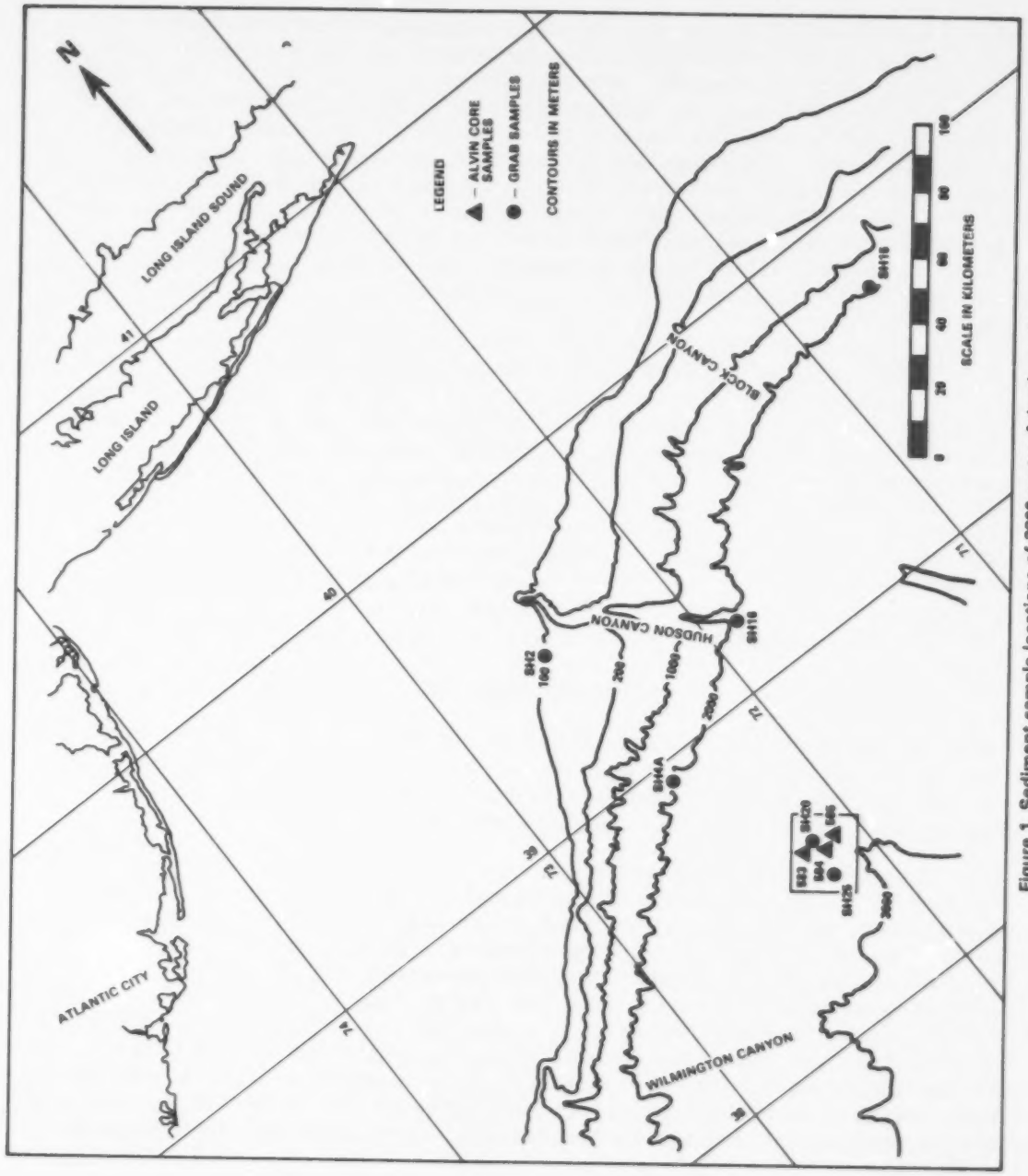


Figure 1. Sediment sample locations of 2800 meter Atlantic nuclear waste site and vicinity taken in 1975 and 1976.

Sample Locations

The sample locations and type recovery of the sediment samples are depicted in Figure 1. In addition to the core samples (to 40 cm depth) in the 2800 meter site area, several Smith-McIntire grab samples were obtained at the waste site, and other locations in the adjacent shelf edge, slope, and submarine canyons, for contrast analyses. A Smith-McIntire grab sample (SH2) was collected from 100 meter depth in the ancestoral Hudson River Valley which existed in this location during the Pleistocene Epoch. Another sample, (SH16), was obtained in the Hudson Canyon at the 2000 meter depth at the foot of the continental slope (Figure 1). Other grab samples were obtained at the 2000 meter contour, approximately 110 kilometers northwest of the Hudson Canyon between Block Canyon and Atlantis Canyon (SH15), and another sample approximately 40 kilometers upslope from the nuclear waste disposal site (SH4A). The comparison of the texture and mineral compositon of these samples with those from the waste dumpsite provide important clues regarding the possible source area and transport pathways of the sediment to the deposition site in the study area.

Analytical Methods

The texture of the sediment was determined by standard sieving and hydrometer techniques and a grain size distribution curve constructed from this data. The sand, silt, and clay size fractions were retained for mineral identification of each size fraction. The mineral identification of the sand-size fraction was determined by standard petrographic techniques while x-ray diffraction, scanning electron microscopy, and chemical techniques were used in the identification of the finer silt and clay-size fractions. X-ray diffraction analysis of the clay minerals in the clay-size fraction was in accordance with Biscaye, 1965 (3). The special techniques necessary to distinguish kaolinite from chlorite, utilized the slow scan techniques proposed by Bicaye, 1964 (4); the areas of the 3.54 A peak were measured for chlorite and the areas of the 3.58 A peak for kaolinite. Carbonate evaluations were made on each of the size fractions by acid leach techniques using 1:4HCl. The fractional components determined on each size fraction was weighted by the grain size distribution curve and the sum recorded as the average for the sample.

The cation exchange capacity determinations were made using a method similar to that of Zaytseva, as briefly described by Sayles and Mangelsdorf (5). The samples were squeezed into a stainless steel device and the pore water collected and analyzed for Na^+, K^+, Mg^{++}, and Ca^{++}; the remaining squeeze cake was split into two parts. One part was used for determination of the residual water content (110°C drying) and the other was leached of residual sea water and exchange cations, using a succession of washes (80% methanol, 1N NH_4Cl adjusted to pH 8 with NH_4OH). The exchange cations were calculated by subtracting the seawater contribution from the total leach solution. The purpose of this involved procedure was to circumvent the exchange cation-seawater reequilibrium (Donnan effect) that occurs during the washing step which proceeds the exchange in the more traditional approach. The pH adjustment and the use of methanol were used to minimize solution of $CaCO_3$ during leaching.

Sedimentary parameters were computed from the grain size curve by standard procedures. Physical parameters, including bulk specific gravity, moisture, porosity, and Atterberg limits were performed in accordance with U.S. Army Corps of Engineers standard soil testing procedures (6). These parameters are used in correlating uniformity of conditions within the sediment and in computations for radionuclide retention.

Any water loss as a result of storing samples for three years before analysis is considered to be inconsequential for most of the parameters tested. The physical parameters and cation exchange capacity, most susceptible to water loss, were performed on samples well contained and observed to be in a highly plastic state so as not to detract from the significant information presented.

Sediment Texture

The sediment texture of the upper continental rise has been described on a regional basis by several investigators using various classifications. Emery (7) and others, stressing grain size, depict the general region as comprised of silt and clay; others stressing the relatively high biogenous content, have described the sediment as globigerina ooze. The texture classification used in this report is in accordance with Shepards (8) classification and particle sizes comply with EM1110-2-1906, (6); sand-size consists of particles between 5.00 and 0.074mm size, silt-size consists of particles between 0.074 and 0.002mm size, and clay-size material consists of particles less than 0.002mm size. A ternary plot of the sand-silt-clay values and sediment description is depicted in Figure 2 and listed in Table 1.

The predominant sediment type at the 2800 meter site is clayey silt with subordinate amounts of silty-clay and silt (Figure 2). Sand is abundant only in the Pleistocene Hudson River sample (SH2) taken at the edge of the continental shelf and the sample from 2000 meter depth between Block and Atlantis Canyons (SH15). Within the 2800 meter study area, the sand content averages 6.3 percent and ranges between 2 and 14 percent; the silt content averages 55.0 percent, ranging between 42 and 76 percent; the clay content averages 38.7 percent ranging between 20 and 50 percent (Table 1). The sediment samples within the 2800 meter nuclear waste disposal site are generally uniform in texture from the surface to 40 cm depth and throughout the area; samples outside the area are less uniform.

Stanley and Wear (9) in a survey of surface sediments on the outer shelf, shelf break, and upper slope between Norfolk and Wilmington canyons have disclosed a transition textural facies which generally parallels the upper continental slope between 250 and 300 meter depth, except at canyon heads. This "mud-line" ($>$ 0.062mm size) , identifies the long-term separation of erosional versus depositional regimes and thus serves as a major energy-level boundary on the upper continental slope. In this investigation, all the sample locations except SH15 have a texture in general compliance with the "mud-line" concept. Sample location SH15 at 2000 meter depth contains sand, silt, and clay in generally similar amounts and this coarser texture may be related to slumping or canyon controlled sedimentation.

Sedimentary Parameters

The sedimentary parameters are statistical measurements derived from the textural grain-size distribution curve and are commonly used in most sedimentological investigations. These parameters have most application in the higher energy zone at shallower depths (10) but are included in this investigation to reflect on the depositional environment, provenance, and for correlation purposes. The sedimentary parameters considered are in accordance with standard procedures and include the median diameter, standard deviation, skewness, and kurtosis. The values for the various station locations are listed in Table 1.

The median diameter is the 50 percentile of the grain size distribution curve. The median diameter for the samples from the 2800 meter site is markedly uniform over the entire area, ranging between 0.002 and 0.005 mm and averaging 0.003 mm (Table 1).

The standard deviation is a statistical measurement of the amount of sorting and is one of the more useful parameters for correlation purposes. The standard deviation of samples outside the waste site ranges from 0.48, for the sandy Pleistocene river sample on the shelf, to 1.39 for the sample at the foot of the continental slope at 2000 meter depth at location SH 15 (Figure 1). More uniform conditions prevail at the waste site. The standard deviation for dive 538 samples at 4 cm intervals from surface to 20 cm depth are respectively: 3.78, 3.20, 4.57, 3.60, and 3.47. Standard deviation for two samples from dive 584 are 2.81 and 3.13 while for dive 585 values are 3.10, 2.96, 2.87, and 2.39 (Table 1). Thus, it is apparent that generally uniform conditions prevail with no apparent trend with depth at the waste site.

In accordance with Friedman's classification (11) for sorting, the samples range from well sorted (Class 1) to extremely poorly sorted (Class 6) with progressively poorer sorting in the seaward direction. The Pleistocene River sample, (SH2), is well sorted (Class 1), while samples SH15 and SH16, at the base of the continental shelf, are moderately well sorted (Class 3). All samples from the 2800 meter waste site and sample SH14 (immediately upslope of the waste site) are extremely poorly sorted (Class 6). The sorting in general becomes poorer as the clay content increases and this parameter correlates well with the "mud-line" concept cited previously.

The skewness is a measure of the direction and degree of overall deviation from symmetry. It is a dimensionless number which expresses the predominance of coarse or fine admixtures and may be positive or negative. Positive values demonstrate that the curve is skewed toward the finer grain sizes and may indicate a stronger depositional environment. Negative values, in turn, show a tail toward the coarser grain sizes and may, therefore, reflect some removal of fines. The skewness values at the waste site range from -1.35 to +2.80 with the highest value at greatest depth from core samples of Dive 585. Near surface samples to 7cm depth at all locations have negative values which indicates a different sedimentation rate than the intermediate depth positive values (Table 1). No trend is apparent from the middle to the bottom of core depth (Table 1).

Table 1. Texture, Physical Properties and Sedimentary Parameters of Sediment Samples, from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity

Sample Location	Lab No.	Percent Dry Weight Sand	Silt	Clay	Bulk S.G. g/cm^3	Water Content (% Dry Wt.)	Atterberg Limits LL	PL	PI	Porosity	Sedimentary Parameters Median (mm)	Std. Deviation	Skewness	Kurtosis
						MCINTYRE/GRAB SAMPLES								
SH-2 (100m)	8	93	7	TR	0.41	27	--	--	--	--	0.420	0.48	-2.00	0.48
SH-4A (2000m)	9	2	61	37	0.72	102	--	--	--	0.73	0.003	3.12	-1.12	2.30
SH-15 (2000m)	10	37	41	22	1.01	61	35	17	18	0.61	0.050	1.39	-1.62	2.25
SH-16 (2000m)	11	7	58	35	1.01	135	--	--	--	--	0.004	0.95	-2.20	2.00
SH-20 (2800m)	14	10	48	42	0.57	137	--	--	--	0.78	0.003	2.70	-1.00	2.85
SH-25B (2800m)	12	4	76	20	0.58	132	--	--	--	--	0.004	3.28	-0.83	3.21
SH-26B (2800m)	13	9	51	40	0.58	131	--	--	--	0.76	0.004	2.70	-0.91	2.48
						DIVE 583 (2800m)								
BOX 2;0-5cm	16	3	52	45	0.69	107	107	31	76	--	0.003	3.78	-1.35	3.20
BOX 2;5-8cm	17	2	53	45	0.76	94	101	32	69	--	0.003	3.20	-0.82	2.48
BOX 2;8-12cm	18	3	62	35	0.66	137	93	32	61	0.75	0.003	4.57	+0.82	3.30
BOX 2;12-14cm	19	-	-	-	0.69	103	100	31	69	--	0.003	3.60	-1.25	3.10
BOX 2;14-18cm	20	3	47	50	0.78	90	93	32	61	--	0.003	3.47	-0.98	3.21
						DIVE 584 (2800m)								
TUBE 2;0-10cm	15	6	59	35	0.54	146	91	32	59	0.79	0.003	2.81	-0.62	2.80
BOX 0-5cm	6	3	52	45	0.67	120	--	--	--	--	0.003	3.13	-1.50	2.28
						DIVE 585 (2800m)								
TUBE 4;0-7cm	22	2	58	40	0.36	240	--	--	--	0.86	0.003	3.45	-1.30	2.50
TUBE 7;0-7cm	1	12	46	42	0.41	209	--	--	--	--	0.003	3.10	-1.00	2.85
TUBE 7;7-12cm	2	10	42	48	1.14	46	--	--	--	--	0.003	2.96	+0.70	3.20
TUBE 7;12-17cm	3	12	48	40	0.86	79	--	--	--	--	0.004	2.87	-0.70	4.20
TUBE 7;17-23cm	4	14	48	38	1.00	62	--	--	--	--	0.004	2.39	+2.80	2.98
TUBE 3;0-5cm	5	7	68	25	0.65	119	--	--	--	0.76	0.004	--	--	--
						DIVE 589 (2800m)								
TUBE 2;0-10cm	23	7	58	35	0.49	166	--	--	--	0.81	--	--	--	--
TUBE 2;20-15cm	7	2	63	35	0.92	71	--	--	--	--	0.007	2.70	+0.40	2.28

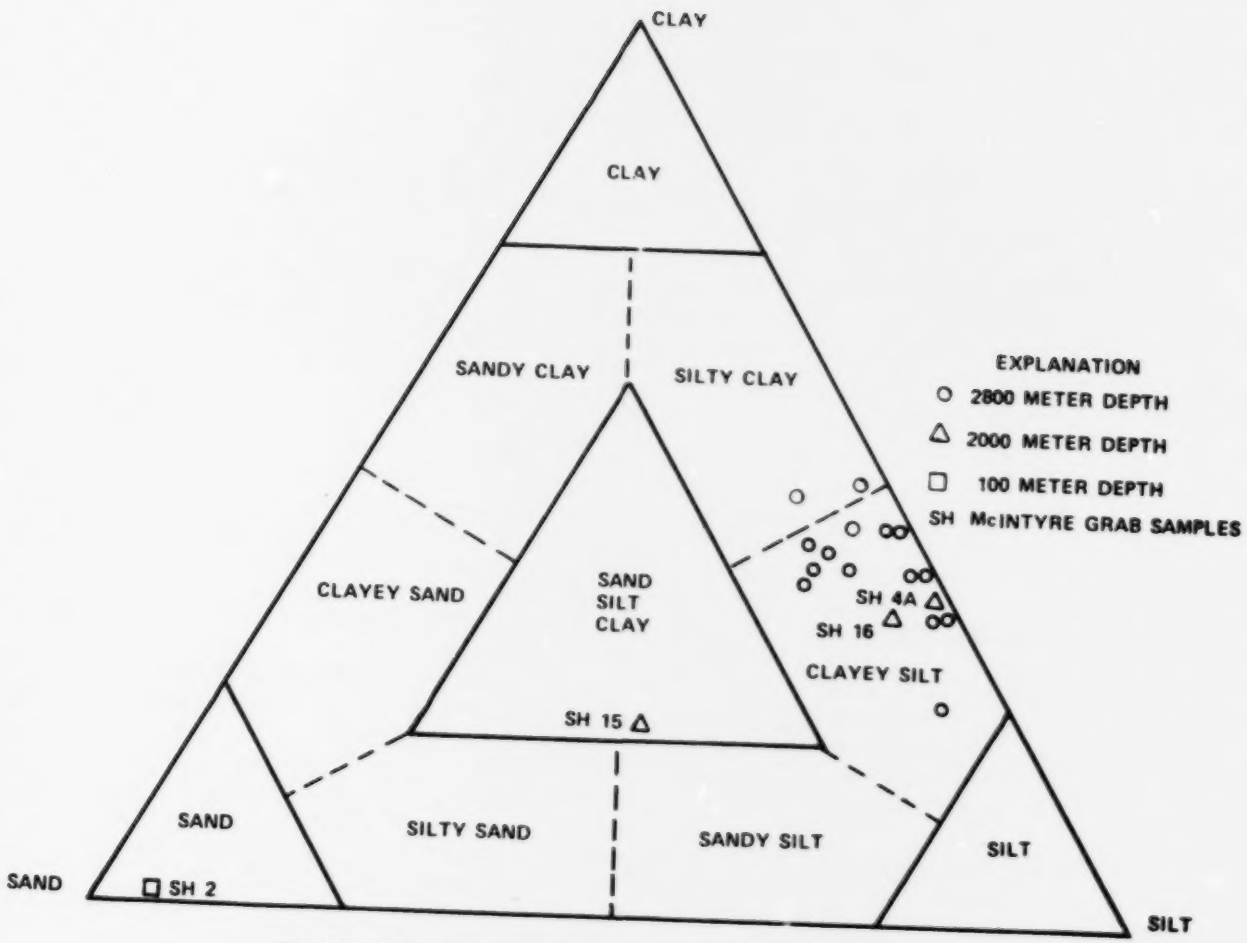


Figure 2. Triangular diagram depicting sediment samples from North Atlantic radioactive waste disposal site. Nomenclature is in accordance with Shepard (1954)

The kurtosis is a measure of the peakedness of the curve. It shows the relationship of the sorting within the main body of the curve to that of the tails. A kurtosis of 1 is normal whereas a kurtosis of 2 is leptokurtic, meaning that it is excessively peaked by a factor of 2; a leptokurtic sample is better sorted in the main body than in the tails. All the samples at the waste site are leptokurtic with values ranging between 2.48 and 4.20 (Table 1). No trend is apparent over the area of the waste site or with depth, but, it is significant that all samples are better sorted in the main body than in the tails.

While sedimentary parameters tell little of the adjustment of the sediments to their present environment or of provenance, these parameters can reflect homogeneous conditions within an area. These parameters enable a relatively inexpensive means of establishing if uniformity of physical conditions prevails within the area investigated.

Physical Properties

Physical properties of the sediments provide basic data necessary for prediction of radionuclide migration in sediment. Some of these physical parameters are listed in Table 1.

The water content (percent dry weight) varies from 209 percent to 62 percent in the 2800 meters study site. Within the 2800 meter site the lowest water content is associated with samples containing the higher sand content. The lowest water content occurs in the sandy samples (SH 2 and SH 15) outside the study area.

The bulk density values of the samples from the 2800 meter site varies between 0.49 gcm^{-3} and 1.14 gcm^{-3} with values depending on the amount of interstitial water. Sample number 22 from dive 585 is a surface sample and has the lowest measured bulk density of 0.36 gcm^{-3} and the highest water content of 240 percent (dry weight) while sample number 2, (5 to 12.5 cm depth) from dive 585 has the highest measured bulk density value of 1.14 gcm^{-3} and a correspondingly low water content of 46 percent (Table 1).

The porosity of the sediment within the nuclear waste dump site ranges between 0.75 and 0.86 with higher values generally correlating with higher water content (Table 1). Both the bulk specific gravity and porosity values are used in computing the radionuclide retention capability of the sediment.

Atterberg Limits are useful in describing quantitatively the effect of varying water content on the consistency of fine grained sediments. The boundaries are defined by the water content which produces a specified consistency. The liquid limit (LL) defines the water content at which the sediment closes with standard mechanical manupliation, while the plastic limit (PL) is the water content at which the sediment begins to crumble or break apart. The shrinkage limit (SL) is the water content at which the soil reaches its theoretical minimum volume after drying from a saturated condition. Atterberg Limits for 6 samples within the 2800 meter waste site, and one sample (SH15) outside the area, are listed in Table 1. All the samples at the nuclear waste site display marked similarity and uniformity

Table 2. Mineral Suite of Sand-Silt-Clay Size Fractions and Average Sediment Composition from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity.

Sample Location	Lab No.	Carbonate				Quartz			Feldspar			Mica			Clay Minerals				Glauconite			Misc.		
		A	B	C	D	A	B	C	A	B	C	A	B	C	A	B	C	D	A	B	C	A	B	C
SH-2 (100m)	8	TR	TR	--	TR	73	78	TR	15	15	TR	5	5	--	--	--	--	--	TR	TR	--	7	2	TR
SH-4A (2000m)	9	10	20	35	25	75	57	TR	10	15	TR	2	6	--	--	--	65	24	2	TR	--	1	2	TR
SH-15 (2000m)	10	5	15	18	14	72	52	TR	20	20	TR	1	8	--	--	--	82	18	1	TR	--	1	5	TR
SH-16 (2000m)	11	50	24	28	27	27	50	TR	15	15	TR	3	8	--	--	--	72	25	3	TR	--	2	3	TR
SH-20 (2800m)	14	95	42	30	42	4	35	TR	1	15	TR	TR	5	--	--	--	70	30	TR	TR	--	TR	3	TR
SH-25B (2800m)	12	99	32	39	36	1	43	TR	TR	10	TR	TR	5	--	--	--	61	12	TR	TR	--	TR	3	TR
SH-26B (2800m) DIVE 583	13	95	37	30	33	4	35	TR	1	10	TR	TR	5	--	--	--	70	28	TR	TR	--	TR	3	--
BOX 2;0-5cm DIVE 583	16	99	40	33	39	1	40	TR	TR	15	TR	TR	3	--	--	--	67	30	TR	TR	--	TR	2	TR
BOX 2;5-8cm DIVE 583	17	99	32	29	30	1	48	TR	TR	12	TR	TR	5	--	--	--	71	32	TR	TR	--	TR	3	TR
BOX 2;8-12cm DIVE 583	18	95	37	22	33	3	44	TR	2	13	TR	TR	3	--	--	--	78	27	TR	TR	--	TR	3	TR
BOX 2;14-18cm DIVE 584	20	90	38	30	36	7	42	TR	2	15	TR	1	3	--	--	--	70	35	TR	TR	--	TR	2	TR
TUBE 2;0-10cm DIVE 584	15	90	45	33	43	8	34	TR	2	10	TR	TR	8	--	--	--	67	24	TR	TR	--	TR	3	TR
BOX 0-5cm DIVE 585	6	57	38	35	37	30	43	TR	10	12	TR	2	5	--	--	--	65	29	TR	TR	--	1	2	TR
TUBE 4;0-7cm DIVE 585	22	90	44	30	39	8	33	TR	1	15	TR	1	5	--	--	--	70	28	TR	TR	--	TR	3	TR
TUBE 7;0-7cm DIVE 585	1	76	30	25	34	12	50	TR	8	12	TR	1	5	--	--	--	75	32	2	TR	--	1	3	TR
TUBE 7;7-12cm DIVE 585	2	60	29	33	35	24	48	TR	10	18	TR	1	3	--	--	--	67	32	2	TR	--	3	2	TR
TUBE 7;12-17cm DIVE 585	3	90	28	30	36	8	53	TR	1	12	TR	1	5	--	--	--	70	28	TR	TR	--	TR	2	TR
TUBE 7;17-23cm DIVE 585	4	90	26	27	35	9	45	TR	1	18	TR	TR	8	--	--	--	72	28	TR	TR	--	TR	3	TR
TUBE 3;0-5cm DIVE 589	5	30	30	30	30	43	48	TR	15	15	TR	1	5	--	--	--	70	18	4	TR	--	7	2	TR
TUBE 2;0-10cm DIVE 589	23	99	33	30	37	1	40	TR	TR	18	TR	TR	7	--	--	--	70	25	TR	TR	--	TR	2	TR
TUBE 2;10-15cm	7	99	32	28	32	1	45	TR	TR	15	TR	TR	5	--	--	--	72	25	TR	TR	--	TR	3	TR

Notes: 1. A = Sand-Size Fraction; B = Silt-Size Fraction; C = Clay-Size Fraction; D = Weighted Average
2. Clay minerals are illite, kaolinite, chlorite, montmorillonite and minor other (See Table 4)
3. Miscellaneous materials include heavy minerals, rock fragments, diatoms, and very minor other.

with depth, whereas the sample outside the area has markedly different values. In themselves, the Atterberg Limits mean little, but they are very useful as indices to significant properties of sediments. For example, the difference between the plastic and liquid limits, termed the plasticity index (PI), represents the range in water contents through which the sediment is in a plastic state and is inversely proportional to the ease with which water passes through the sediment. Thus, the low PI value of 18 for the sample outside the study site (SH15) reflects a more permeable sediment as compared to the range of PI values of 59 to 76 for the less permeable samples within the 2800 meter nuclear waste site. The Atterberg limits are also useful in identifying and classifying sediments and for correlation purposes.

Sediment Composition

The mineral composition of the sediment varies considerably within the sand, silt, and clay fractions. Since both mineral composition and grain size are important factors in assessing the radionuclide retention capability, the sediment in this investigation is treated in as quantitative manner as possible in order to obtain realistic values. The fractional components are reported for each size fraction and the average composition of the sediment is the sum of these fractional components reduced to their representation in the total sample as shown on the grain size distribution curve.

The average mineral composition for 60 samples from the Atlantic upper continenatal rise of the mid-Atlantic States by Hathaway (12) is as follows: quartz, 17 percent; feldspar, 12 percent, carbonate, 18 percent; clay minerals, 53 percent, hornblende, trace. As compared with the 2800 meter site the carbonate content is greater (37 percent) and the clay content less (30 percent).

The carbonate is probably greater at the 2800 meter site because of its location farther seaward on the upper continental slope. This increase of carbonate in a seaward direction off the North Atlantic continental shelf has also been demonstrated by Turekian (13).

The sediment composition is important in any assessment of the radionuclide retention capabilities of the sediment. In order to group materials of similar chemical behavior as regards their barrier potential to migration of radionuclides from nuclear waste leachate, the sediment is classified into a biogenous group, terrigenous sand and silt group, and a clay mineral group.

Biogenous Materials

Biogenous materials, originating from the ocean environment, comprise more than a third of the sediment. Reported as carbonate and miscellaneous diatoms in Table 2, these materials are shown to be most abundant in the sand fraction but they are also abundant in all sieve sizes (Table 2). The calcareous foraminifera comprise the bulk of the sand (Figure 3) and are predominantly the planktonic genus Globigerina.

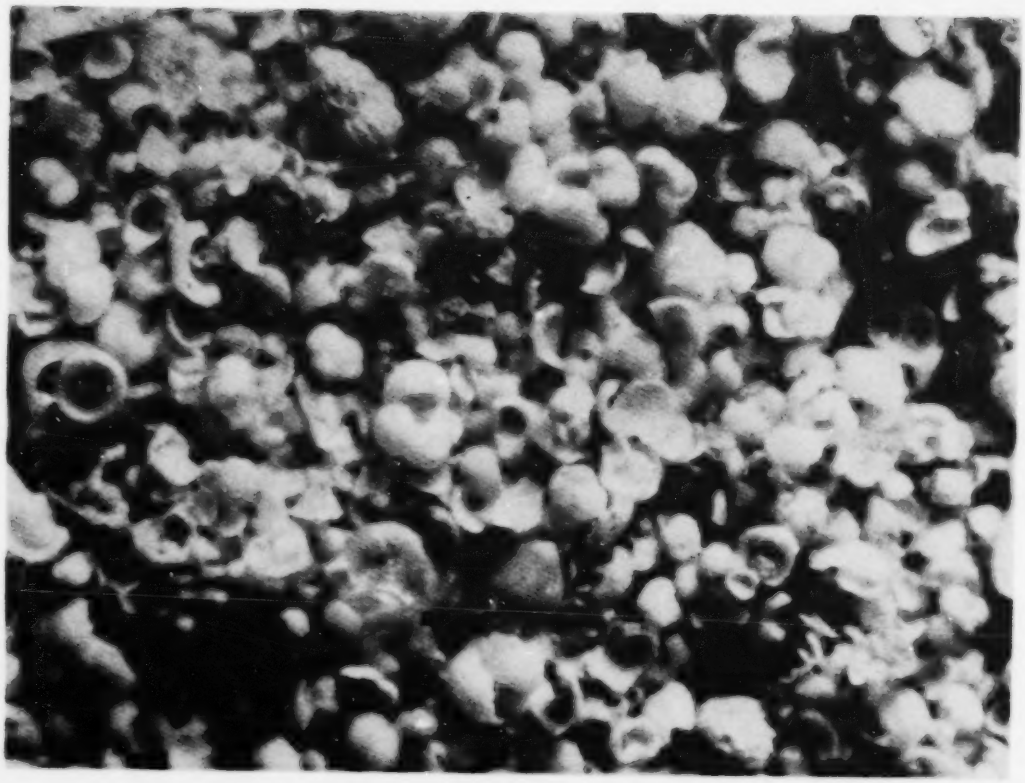


Figure 3. Photomicrograph (26X) of sand-size fraction of sediment core 7, 5-12 cm depth, from Dive 585 in the 2800 meter Atlantic nuclear waste disposal site. Foraminifera comprises the predominant portion of the sand.

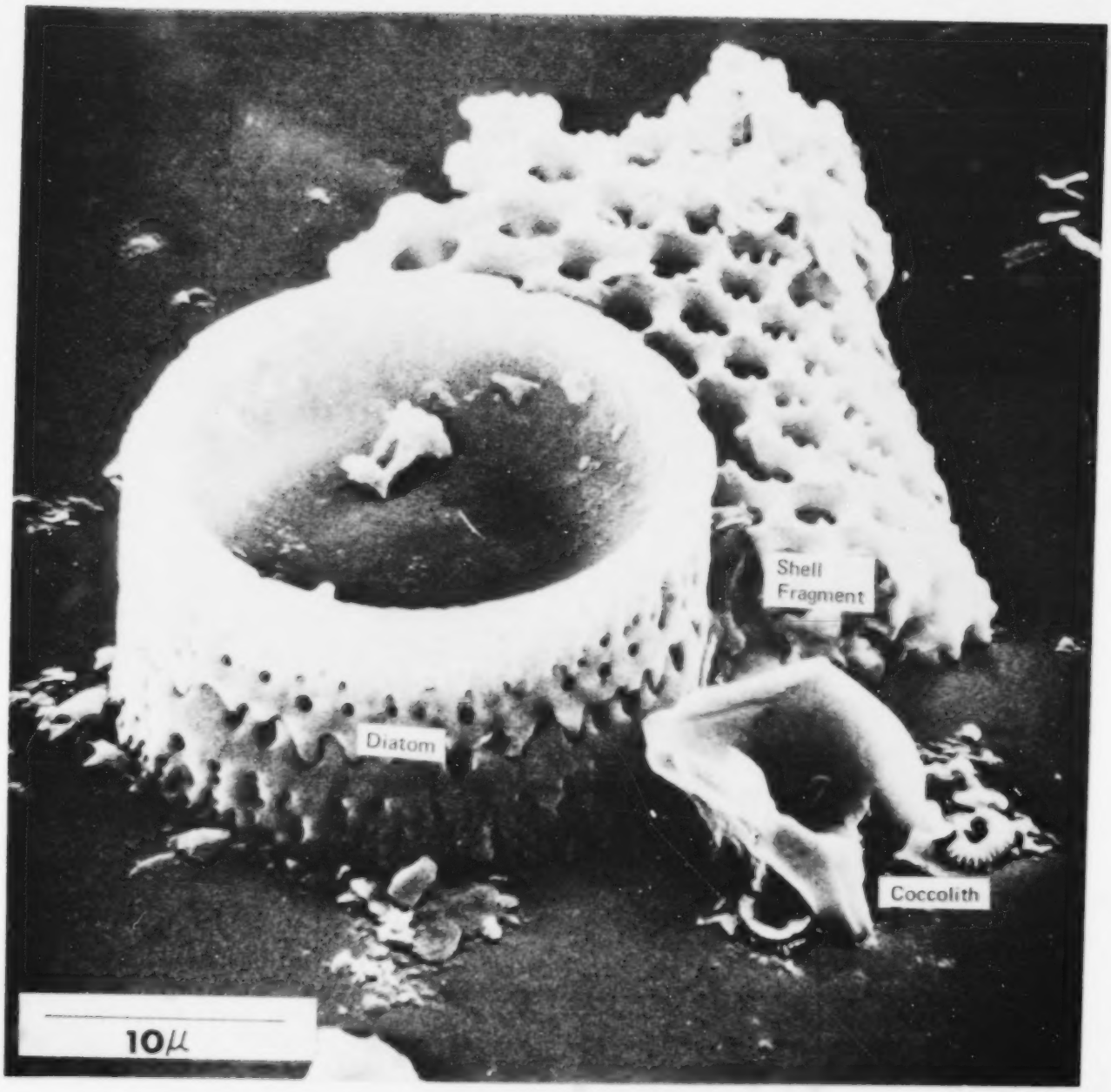


Figure 4. Scanning Electron Microgram (4800X) of silt fraction from 2800 meter depth at dive location 584 (0-5 cm depth) in Atlantic Nuclear Waste Dumpsite. The diatom and shell fragment (upper right) constitute the larger biogenous material, while Coccoliths (lower right) constitute the smaller biogenous materials.

Figure 5. Scanning Electron Micrgraph (2900X) of Silt Fraction from dive 585 (0-5 cm depth) in 2800 meter Atlantic Nuclear Waste Dumpsite. Broken, spherical, calarcous, Globerigerina Foraminifera (upper right) and Coccoliths comprise the predominate biogenous silt fraction.

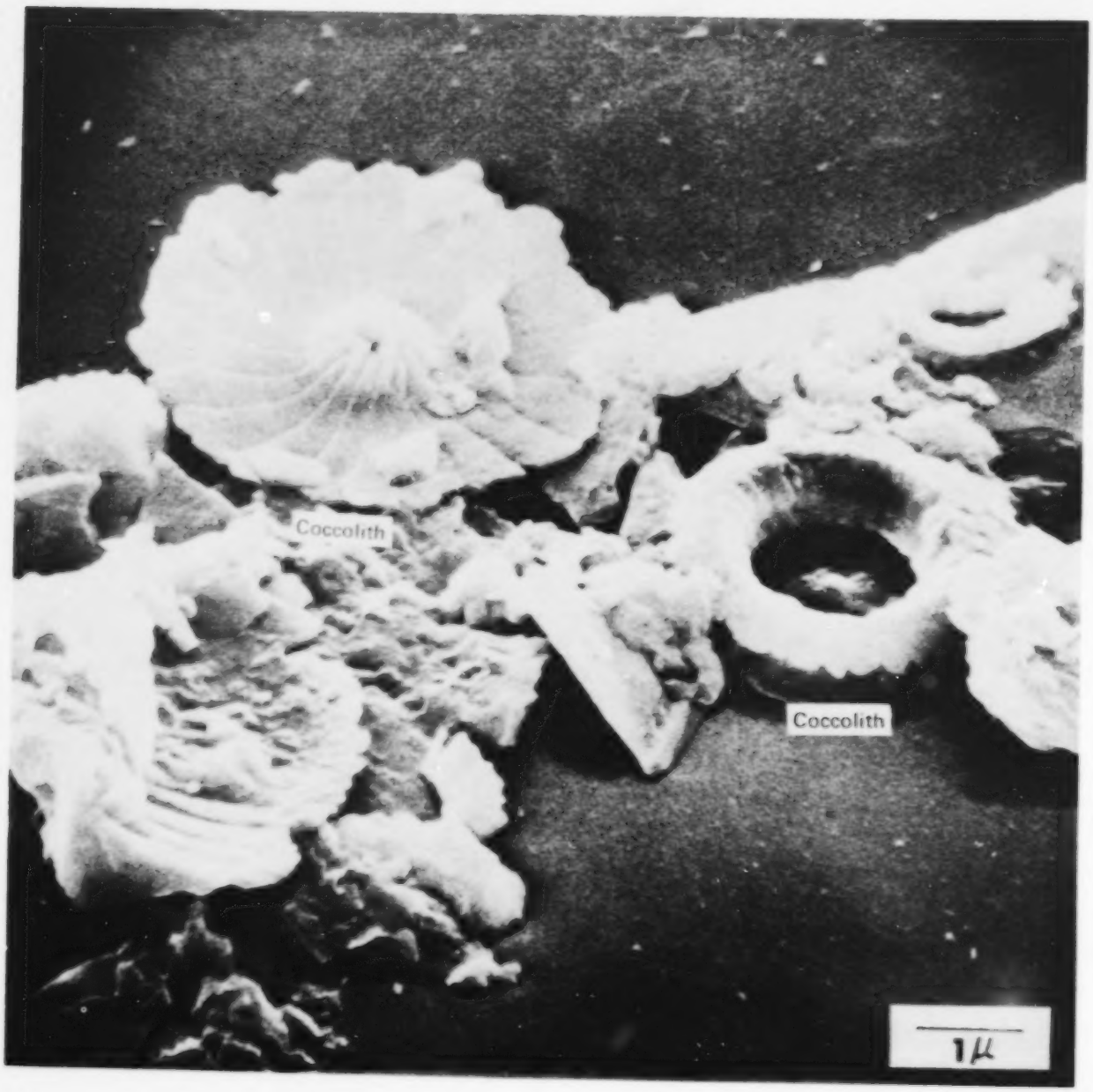


Figure 6. Scanning Electron Micrograph (15,000X) of clay-size Coccoliths from dive location 585 (0-5 cm depth) 2800 Meter Atlantic Nuclear Waste Dumpsite;

Figure 7. Scanning Electron Micrograph (14,000X) of calareous Coccolith tests from dive 585 location (15 cm depth) in 2800 Meter Atlantic Nuclear Waste Dumpsite.

Calcareous planktonic coccolith tests (less than 30 microns in diameter) constitutes the biogenous material of the lower silt and clay-size fraction (Figures 4, 5, 6, and 7). Minor calcareous corallites and siliceous diatoms also occur in the upper silt-size fractions but these microorganisms seldom comprise more than a few percent of the biogenous fraction.

Certain radionuclides, such as strontium-90 could possibly exchange for some of the calcium cation of the carbonate fraction and thus the biogenous material has some potential for radionuclide retention by the sediment.

Terrigenous Materials

Terrigenous materials include all the non-biogenous materials except the clay minerals and the predominant amount occurs in the silt-size fraction. The terrigenous materials are predominantly quartz and feldspar but also includes minor amounts of mica (biotite, muscovite, and chlorite) and very minor amounts of detrital heavy minerals and glauconite (Table 2). The glauconite generally comprises less than one percent of the sediment and while marine in origin this material is largely derived as detrital material from erosion of Cretaceous formations of the adjacent continent.

Special detail to the varieties of feldspar and detrital heavy minerals lend support to the source of the sediment but most of these materials do not contribute significantly to radionuclide retention. Heavy minerals from the 2800 meter site comprise less than one percent of the terrigenous material; fraction representation is listed in Table 3. The ratio of heavy mineral species reflect sources from the mineral provinces delineated on the adjacent continental shelf and boundries between these provinces are essentially perpendicular to the shelf break. The ratios of these minerals will be used in a later section to reflect on the source area and the hydrodynamic agencies involved in effecting sediment deposition at the 2800 meter site.

Pebble size chert and quartzite rock particles are unique to the Pleistocene Hudson River sample (SH2) while diagnostic gabbro rock particles of upper sand size (4-5mm) occur in sample SH15 from the bottom of the continental slope between Atlantis and Block Canyons. The presence of these rock particles in either pebble or upper sand size is of correlative value to distinguish the New England coast sediments from those originating in the region of the New York Bight.

Clay Minerals

The clay minerals comprise approximately a third of the sediment at the 2800 meter site and constitute the bulk of the clay-size fraction. Their unique dimensions (less than 2 microns diameter), large surface area, high cation exchange capacity, and high sorption potential for radionuclides makes the clay minerals the most significant as regards the potential of the sediment to act as a barrier to the migration of radioactive waste.

Illite is the principal mineral of the clay-mineral suite with a range between 50 and 60 percent. Kaolinite and chlorite occur in generally similar proportions in the clay-mineral suite with ranges between 12 and 30 percent (Table 4). Because of the difficulty in obtaining a clear resolution of

Table 3 - Heavy Mineral Analysis of Sand-Size Sediment from the 2800 Meter Atlantic Nuclear Waste Disposal Site and Vicinity

Field Location	SH2 100m	SH15 2000m	Dive 583 2800m	Dive 584 2800m	Dive 585 2800m	Dive 585 2800m	Dive 585 2800m	SH25 2800m	SH26 2800m
Lab No.	8	10	21	15	2	4	5	12	13
				% Heavy Mineral Fraction					
Ilmenite	27	12	18	17	21	14	20	20	22
Magnetite	3	4	5	5	5	5	2	3	5
Amphibole/ Pyroxene	12	31	23	28	22	20	29	28	25
Garnet	33	20	38	29	30	36	25	26	24
Staurolite	4	9	4	5	4	7	4	4	5
Epidote Group	1	5	2	2	5	4	2	4	4
Zircon	9	8	3	5	4	4	9	6	4
Sillimanite	2	2	2	2	2	3	2	3	3
Kyanite	1	1	1	1	1	1	1	1	2
Rutile	5	2	1	2	1	1	4	1	1
Tourmaline	1	4	2	2	3	3	1	3	3
Miscellaneous	2	2	2	2	2	2	2	1	2
				Garnet-Staurolite Ratio					
G/S	8	2	9	6	8	5	6	7	5

Notes. 1. Miscellaneous mineral varieties include monazite, apatite, and very minor other minerals.

Table 4. Clay Minerals of Clay-Size Fraction of Sediments from the 2800 meter Atlantic Nucelar Waste Disposal Site and Vicinity

		% Clay Mineral Suite			
Location	Lab No.	Illite	Kaolinite	Chlorite	Montmorillonite
SH4A (2000m)	9	47	30	16	7
SH15 (2000m)	10	60	19	18	5
SH16 (2000m)	11	60	20	15	5
SH20 (2800m)	14	52	20	18	10
SH25B (2800m)	12	51	20	18	9
SH26B (2800m)	13	52	20	20	8
DIVE 583 BOX 2, 0-5cm	16	54	21	15	10
DIVE 583 BOX 2, 5-8cm	17	56	18	18	8
DIVE 583 BOX 2, 8-12cm	18	58	16	16	10
DIVE 583 BOX 2, 12-14cm	19	58	18	16	8
DIVE 583 BOX 2, 14-18cm	20	54	18	18	10
DIVE 583 TUBE 1, 22.5-30	21	55	23	12	10
DIVE 584 TUBE 2, 0-10cm	15	50	21	21	8
DIVE 584 BOX 1, 0-5cm	6	58	17	17	8
DIVE 585 TUBE 4, 0-7cm	22	58	17	17	8
DIVE 595 TUBE 7, 0-7cm	1	52	18	18	12
DIVE 585 TUBE 7, 7-12cm	2	54	23	15	8
DIVE 585 TUBE 7, 12-17cm	3	52	20	20	8
DIVE 585 TUBE 7, 17-22cm	4	54	19	19	8
DIVE 585 TUBE 3, 0-5cm	5	55	18	17	10
DIVE 589 TUBE 2, 0-10cm	23	57	20	17	6
DIVE 589 TUBE 2, 10-15cm	7	50	30	12	8

Note: 1. Chlorite fraction includes trace amounts of vermiculite.
2. Montmorillonite includes mixed-layer clay (chlorite-montmorillonite)
3. Carbonate comprises between 15 and 39 percent of the clay fraction.

chlorite and kaolinite on x-ray diffractograms both the slow scan speed and the regular scan x-ray diffraction techniques were employed for more positive identification of these two minerals. The values of the clay minerals at the nuclear waste site are in general agreement with the values obtained by Hathaway for the upper continental rise sediments in this region (12). Dayal, et al. (14), found chlorite to be slightly in excess of kaolinite at the nuclear waste disposal site, however, the sum of both kaolinite and chlorite are in general agreement in all the investigations cited. Montmorillonite and mixed-layer montmorillionite clay occur in subordinate amounts at all site locations with values generally less than 10 percent of the clay-mineral suite. The clay mineralogy is fairly consistent throughout the 2800 meter Atlantic nuclear waste disposal site.

Characteristics of Clay Minerals

In order to make use of clay minerals in investigations concerning nuclear waste disposal, it is necessary to have a general concept of the chemical and structural make up of the common clay minerals. The following treatment is presented for those readers having little familiarity with the common clay minerals at the Atlantic sites.

The common clay minerals are hydrated silicates comprised of thin sheets held together by predominantly ionic bond; each sheet consists of planes of cations (silica, aluminum, magnesium, or iron) in which the individual cation is surrounded by either four (top sheet) or six (lower sheet) oxygen and hydroxyl ions. The main subdivisions of the clays are based on how these sheets are stacked as follows:

a. Kaolinite of 1:1 clays contain one silicia sheet (silicon-oxygen tetrahedron) and one sheet of either aluminum, magnesium, or iron (aluminum-oxygen-hydroxol octahedron).

b. Illites and montmorillonites of 2:1 clays contain two silica sheets which are on either side of an aluminum, magnesium, or iron sheet. In addition, the montmorillonites contain one or two water sheets.

c. Chlorite of 2:2 clays contain two silica sheets which alternate with two magnesium or iron sheets; the latter have bonds of unequal strength.

Typical clay structures have a thickness of 7 Angstroms as in the case of kaolinite, 10 Angstroms for illite, 14 Angstroms for chlorite and 12 to 14 Angstroms for montmorillonite. Water between montmorillonite tetrahedral layers increases the thickness 2.5 to 4 Angstroms depending on presence of one of two water layers fixed respectively by Ca^{++} and Mg^{++} or Na^{+}. The K^{+} fixed to illite, does not add much thickness to the clay structure because it fits into the hexagonal hole in the silica tetrahedrom sheets. Chlorite contains no interlayer water but is similar to montmorillonite in size due to a brucite layer. Isomorphous substitution may take place in the clay mineral structure with the amount depending on charge, ionic radius, coordination number or solubility of the participating ions. Common substitution in clay minerals might involve an Fe^{+++} and Al^{+++} substitute for Si^{++++} in the tetrahedral layer while Mg^{++} and Fe^{++} substitute for

Table 5. Cation Exchange Capacity of Sediment from 2800 Meter Atlantic Nuclear Waste Disposal Site.

		Exchangeable Cations (meq/100g)				
Field No.	Lab No.	Na^{+}	K^{+}	Mg^{++}	Ca^{++}	$\sum$Cations
SH26	13	7.0	0.8	4.1	3.3	15.2
SH20	14	8.0	1.6	4.3	3.5	17.4
Dive 584	15	11.3	2.6	6.3	5.2	25.4
Dive 583	16	9.4	2.1	5.3	4.0	20.8
Dive 585	21	6.9	1.4	3.4	3.3	15.0
Dive 589	23	7.3	1.7	4.2	3.6	16.8

Notes: 1. Method in accordance with Zaytseva non-rinse technique. Tested by K. Beck.

Al^{+++} in the octahedral layer. The result of a lesser valence cation substitution for a higher valence cation is a negative (-) charge. Most of the charge on kaolinite is usually along the edge but for montmorillonite is along the surface. Cations, such as Ca^{++}, Na^{+}, H^{+}, Mg^{++}, and K^{+}, are adsorbed on these positions to neutralize the charge when the clay particle encounters a cation-rich environment or receives radionuclides from waste drums. Radioactive waste contains considerable strontium and cesium which could substitute for calcium or sodium under proper environmental conditions.

Cation Exchange Capacity

The measurement of cation exchange capacity is correlative with the ability of a sediment to adsorb radionuclides from a radioactive waste source. This measurement is expressed in terms of milliequivalents per 100 grams and varies for the different clay minerals. The general range in cation exchange capacity of the common clay minerals, in milliequivalents, is 3-50 for kaolinite, 10-40 for chlorite, 10-40 for illite, and 80-150 for montmorillonite. Thus, sediment rich in montmorillonite would have a higher cation exchange capacity than a kaolinite-rich sediment.

The cation exchange capacity ranges between 15.0 and 25.4 meq/100g at the 2800 meter site (Table 5). Dayal, et al., (14), reporting on the cation exchange capacity with depth for cores taken by the SRV Alvin, found a range between 35 to 55 meq/100g. No significant trend in the total cation exchange capacity with depth of burial was observed and it was concluded that fixation of exchangeable cations does not occur during early diagenesis.

The presence of organic matter in the sediment could also influence the cation exchange capacity of a sediment. Experiments in recent soils reveal cation exchange capacity values of 150-500 meq/100g for organic matter. The organic matter at the waste site, however, is probably negligible since values of total organic carbon reported for this section of the ocean floor are on the order of 0.05 percent of the sediment (Emery and Uchupi (10).

Distribution Coefficient (Kd) Considerations

The complex physicochemical reactions that occurs between radionuclides in solution and the ocean sediment is termed sorption. Sorption includes such phenomena as adsorption, ion exchange, colloid filtration, reversible precipitation, and irreversible mineralization. Sorption is expressed in terms of the distribution coefficient (Kd) which is the ratio of the sorbed and dissolved fraction of the radiosotope in the sediment. Knowledge of the Kd of a given radionuclide in sediment, together with information concerning the bulk density and porosity of the *in situ* state, may be used to estimate the retardation factor, Rd, for groundwater transport of that radionuclide using the equation $Rd = 1 + KdP/E$, where p is the bulk density of the medium and E is the porosity. The bulk density used in the equation must be reported in units of g/cm^3 to obtain a dimensionless Rd.

The bulk density of the samples from the 2800 meter nuclear waste disposal site range between 0.49 to 1.14 g/cm^3 with a general average of 0.68 g/cm^3. The porosity has a relatively narrow range between 0.75 and 0.81.

Considerable Kd values for continental geologic formations or soils have been reported in the literature, however, such data is not directly applicable to the ocean sediment environment. Also much of this data is subject to inadequate characterization of the solid medium or to inappropriate experimental design of the testing method. Some laboratory Kd values for strontium-90 and cesium-137 using clay minerals have been reported by Ames and Rai (15). Such data may possible compare to those expected in ocean sediment; this data is listed below for clay minerals.

Clay Minerals	Kds	
	Sr-90	Cs-137
Montmorillite	104	4,400
Kaolinite	15	45
Illite	100	400

Heath(16), reporting on preliminary results of distribution coefficient experiments on montmorillonite-rich Pacific Ocean deep sea sediment indicated Kd values for cesium 137 varies from 3000 to 20,000 and for strontium 90 values range from 100 to 6000. As contrasted to continental deposits, the marine clays appear to be superior in retaining radionuclides. Much needs to be done, however, to get reliable data on the interactions between dissolved waste components and deep-sea sediments. Kd measurements in the laboratory have been conducted in an oxidizing environment, whereas in reality, ocean sediment is largely a reducing environment. Bondietti and Francis (17) have demonstrated the role of the oxidation state in controlling the solubility of technetium and neptunium from a nuclear waste source; in a reducing environment both radionuclides have high Kd values yet in oxidizing conditions both elements are highly mobile and not readily retained by the geologic media. The pH and Eh are also important factors governing solubility. Both pH and Eh (oxidation-reduction) measurements should be made as soon as the sediment sample is received on board the vessel. Measurements for Kd's in the laboratory should match these measured field parameters.

In addition to the need for laboratory controlled environmental conditions to match the *in situ* conditions at a disposal site for accurate Kd assessment, Seitz, et al., (18), in recent column infiltration studies of cesium and other radionuclides on shales and other rock types, has warned of other factors that also influence radionuclide retention. Some of these factors which may have application to ocean sediment considerations include

(a) flow rates and dispersive characteristics, (b) nuclide-bearing colloids that react slowly with lithic material, (c) migrating clay particles with adhered radionuclides, (d) chelating of soluble organic compounds, and (e) effects of coexisting species of radionuclides.

Sediment Source Considerations

The sediment deposition is a function of both source area and transport agencies. Each of these factors are important considerations in any analysis of the pathway migration of radionuclides from waste drums at the 2800 meter site as well as in any potential future disposal sites. Examination of the sediments at the 2800 meter site reflect both their source and processes of deposition.

Submarine canyons have been cited by several investigators as sediment traps that funnel terrigenous sand to ocean depths (10, 19, 20). Stanley, et al., (21) concludes that turbidity currents moving down the canyons release a considerable portion of their load on the upper and lower continental rise. Observations and investigations also cited by Emery and Uchupi (10) would suggest that the terrigenous sand in the sediment at the 2800 meter nuclear waste site eminates from a source largely from the Hudson Canyon and lesser amounts by contour currents from the northeast.

That the terruginous sand-size sediment at the 2800 meter nuclear waste site has its origin from nearshore continental shelf sand funneled down the Hudson Submarine Canyon can be assessed by diagnostic heavy minerals in the sand fraction. Several heavy mineral provinces and subprovinces on the continental shelf of the mid-Atlantic and New England states have been delineated by several investigators (10, 19, 22-29). The Hudson Canyon receives the terrigenous sands from the central New Jersey Coast on the south (30) and the Long Island coastal region on the north as a result of longshore currents directed to the New York Bight (Figure 8). This provides a characteristic heavy-mineral suite that is similar to the adjacent continental shelf but differs from the heavy-mineral suite delivered by canyons draining the New England coast. This is apparent in the comparison of the heavy-mineral suite of samples SH15 and SH2 (Table 3). Sample SH15, located at the base of the continental slope between Atlantis and Block Canyons, contains a garnet-staurolite ratio that correlates with the characterization of the New England shelf heavy mineral province reported by Ross, (23), whereas sample SH2 has a higher garnet-straurolite ratio which is correlative with the heavy mineral province centering about the New York Bight and the Hudson Canyon (23). Thus the garnet-staurolite ratios of the 2800 meter nuclear waste site range between 5 and 9 (Table 3) and these values are typical of the mid-Atlantic province centering about the New York Bight. Such data correlates with hydrodynamic considerations previously cited and it suggests the source of the inorganic portion of the sand fraction may be from the adjacent continental shelf with relatively short transport distance from the Hudson Canyon to the deposition site.

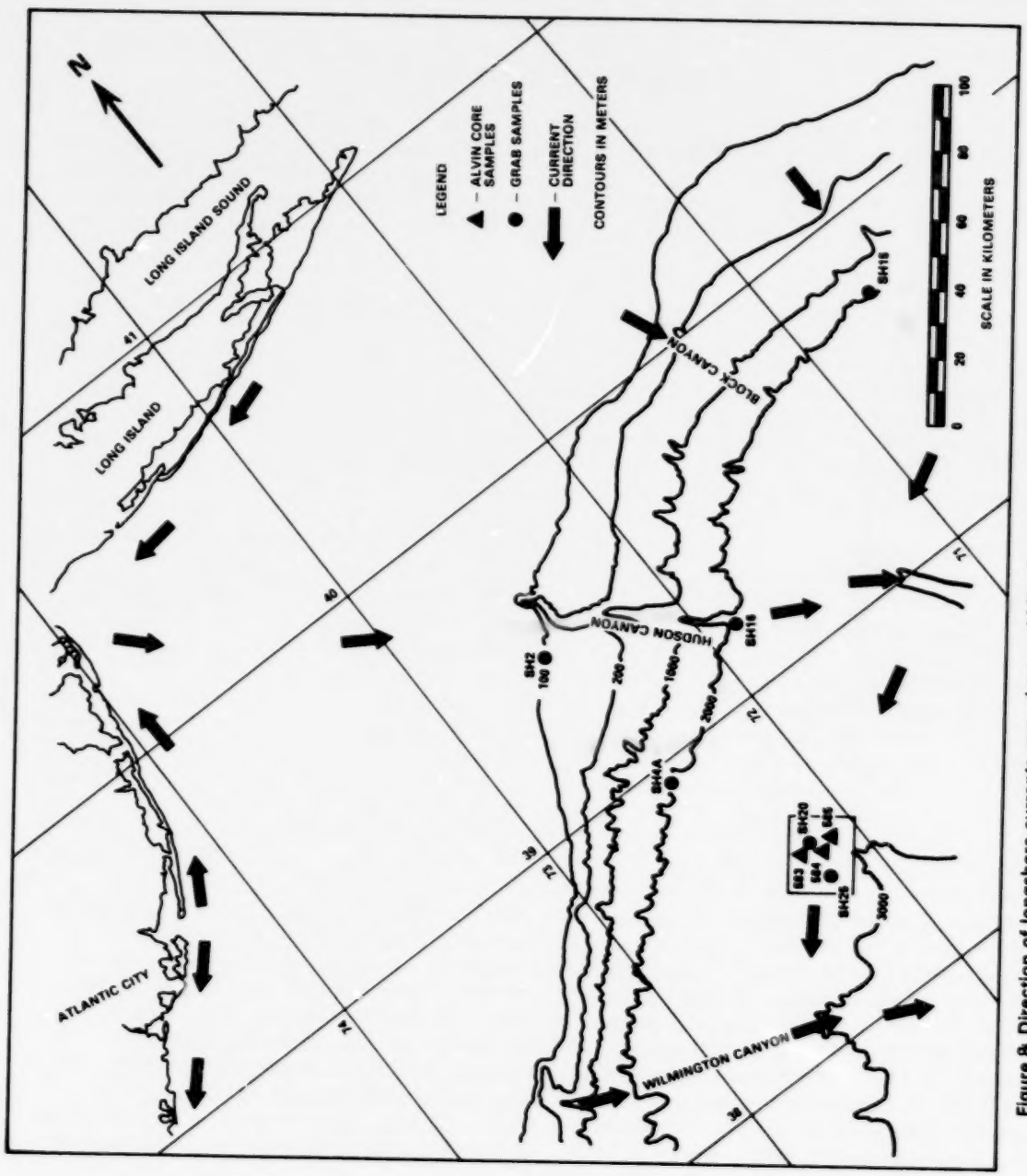


Figure 8. Direction of longshore currents near shore, turbidity flow down the submarine canyons, and predominant bottom flow in vicinity of 2800 meter Atlantic waste site.

That the sediment funneled down Wilmington Canyon on the southwest side of the 2800 meter study area is not transported northeasterly is suggested by heavy mineral studies by McMaster (26) and Neiheisel (24). The sediment source of terruginous sands transported by turbidity currents in Wilmington Canyon appears to be from the areas controlled by longshore currents operating along the mid-New Jersey Coast toward Cape May (30) and from longshore currents directed north along the Delaware Coast toward Cape Henlopen (31), (Figure 8). Twitchell, et al., (32) cite evidence that Wilmington Canyon extended to Delaware Bay and thus the heavy-mineral suite would probably reflect a mixed New Jersey suite delineated by McMaster (26) and the Delaware coast suite delineated by Neiheisel (24) in investigations near shore. Alexander (25) and Kelling, et al (28) in investigations on the outer shelf also indicate a change in sillimanite and pyroxenes in proximity to the Wilmington Canyon. The influence of the Wilmington Canyon terrigenous sediment is also not apparent at the 2800 meter nuclear waste site for the heavy mineral assemblage postulated. However, more definitive sampling must be conducted to better define this southwestern boundary of that portion of the upper continental rise containing the 2800 meter nuclear waste site.

Investigators in the deep-sea submersible ALVIN have recently provided further evidence supporting transport of sediment in a southwesterly direction along the upper continental rise at the 2800 meter nuclear waste site. Photographs by Rawson and Ryan (2), reveal (a) nuclear waste drums with rust and sediment on the lee side of drums extending in a southwesterly direction and (b) 40 cm high Umbella bending in a southwesterly direction in compliance with bottom currents. Current meters also recorded a westerly direction and velocities up to 10cm/sec.

Sedimentation Processes Affecting Radionuclide Distribution in Sediment

The sediment can only be an effective barrier if the nuclear waste drums are surrounded by the sediment. Leakage from an exposed area of the drum would "short circuit" the sediment trap by moving radionuclides directly into the water column. Thus any consideration of the capability of the sediment at the site to retain radionuclides must also consider the capability of waste drum confinement by burial prior to the release of leachate after rupture or corrosion of the drums. Even if buried, the bioturbation effected by burrowing organisms may "short circuit" the sediments potential to entrap the radionuclides by the sorption process.

The 2800 meter site contains nuclear waste drums were deposited on the ocean floor a few decades ago and early indications are that relatively few of the drums have ruptured or corroded excessively. The sedimentation rate at the site according to Rawson and Ryan (2), is 6.8 cm per 1000 years for the recent Epoch, i.e., for the last 11,000 years. Thus the amount of sediment accumulation around the drums is a result of the drum sinking into the soft sediment, the vertical "blanketing" by sediment from above and the deposition effected in "craig and tail" like deposits on the leeward side of the drum as a result of prevailing bottom contour currents. Any meaningful radiological survey of the fate of radionuclides leached from ruptured waste drums at the 2800 meter site must consider the retention of radionuclides by sorption as

well as the potential dispersal by "short circuit" mechanisms such as bioturbation hydrodinamic mechanisms or direct contact with the water column. Preliminary surveys by Dayal, et al. (14) from radiometric measurements of cores taken in 1975 in proximity to waste drums suggest that concentrations of both cesium-137 and cesium-134 reflect release from nearby waste drums. A model developed to describe the observed radioactive cesium distribution, indicates a faster mixing rate through the vertical than is considered possible by migration of the radionuclide via molecular diffusion, through pore waters; an eddy diffusion process is suggested that may relate to bioturbation, hydrodynamic mechansms, or other short circuit mechanisms.

Summary and Conclusions

The sediment from the 2800 meter Atlantic nuclear waste disposal site and vicinity has been analyzed for texture, mineral composition, physical parameters, and geochemical parameters to gain basic information as relates to the ability of the sediment to act as a barrier to the migration of radionuclides from the nuclear waste drums.

The texture of the sediment is uniform throughout the waste site to 30 cm depth and is predominantly a clayey-silt with minor amounts of silty-clay. The sand-size fraction comprises from 2 to 14 percent of the sediment and consists predominantly of biogenous calcareous foraminifera tests and minor amounts of quartz, feldspar, mica, glauconite, diatoms, and detrital heavy minerals. The predominant silt fraction (42 to 76 percent) consists of biogenous carbonate (foraminifera, coccoliths and minor other) and detrital terrigenous quartz, feldspar, mica, and minor other. The clay size fraction consists of a clay mineral-suite and biogenous carbonate (largely coccoliths). The clay mineral-suite, comprising 65 to 78 percent of the clay-size fraction, is comprised of illite (50-57 percent), kaolinite (16-30 percent), chlorite (12-21 percent), and montmorillonite (5-12 percent).

The total cation exchange capacity of the sediment ranges between 15.2 and 25.2 percent with no apparent variation with depth. The exchangeable cations in order of abundance are Na^{+}, Mg^{++}, Ca^{++}, and K^{+}. The relatively high cation exchange capacity of the sediment predicts relatively high coefficient distribution, (Kd), values to be expected in the sediment. Bulk specific gravity and porosity values determined for the sediment samples can be used to compute the radionuclide retention, (Rd), of the sediment if the distribution coefficient is known. Comparisons of marine sediment Kd's and terrigenous samples suggest that highest radionuclide retention occurs in the marine sediments.

The deposition at the waste site is controlled by the vertical "rain" of micro fossils, contour current movement of sediment in a southerly direction, and some movement of sediment down the slope by the effects of downslope movement or other mechanisms. That the terrigenous sand and silt fraction is largely controlled by sediment funneled down the submarine canyons with "plumes" of this sediment made available for directional transport by prevailing bottom currents is evident in the heavy-mineral suite at the site. The heavy-mineral suit is typical of the provinance of the New York Bight at the head of Hudson Canyon and the areas controlled by longshore currents operating along the coast.

The ability of the nuclear waste drums to be covered by sediment is essential if the sediment is to act as a "trap" for the radionuclides. Exposed waste drums effect dispersal of the radioactive leachate to the water column. Short circuiting of the sediment "trap" may also be effected by bioturbation or other disturbances of the sediment and migration will be effected by the pH, Eh, and other environmental factors.

Acknowledgements

This work was sponsored by the Environmental Protection Agency, Office of Radiation Programs, pursuant to the Marine Protection Research Sanctuaries Act of 1972, as amended (Public Law 92-532) with R.S. Dyer project officer. Laboratory equipment to perform sediment analysis was provided the writer by the U. S. Army Corps of Engineers, South Atlantic Division Laboratory, Marietta, Georgia under an interagency agreement. Supporting tests, including grain size distribution curves, porosity, bulk specific gravity, and Atterberg Limits, were performed by the Corps of Engineers and scanning electron micrographs were obtained by sub contractual agreement with the Georgia Tech Engineering Experiment Station. Cation exchange capacity analysis were made by Dr. Kevin Beck of the School of Geophysical Sciences at Georgia Tech. Special thanks is extended to Dr. Eric Force, U.S. Geological Survey, Reston, Va, for use of laboratory facilities and petrographic microscope for the examination of heavy mineral, and to Dr. Robert Carney of the Smithsonian Institute, for verification of microfauna on scanning electron micrographs. I also wish to thank Dr. Charles Weaver, of Georgia Tech, Dr. Kenneth Czyscinski of Brookhaven National Laboratory, and Dr. Alexander Williams of the Environmental Protection Agency for their careful review and helpful suggestions in the preparation of this report.

REFERENCES CITED

(1) PRATT, R.M., Atlantic continental shelf and slope of the United States - physiography and sediments of the deep-sea basin, Geol. Survey Prof. Paper 529-B, 44p. (1968).

(2) RAWSON, M.D., and RYAN, W.B.F., Geological observation of deepwater radioactive waste dumpsite - 106, EPA Report 520/9-78-001, in press

(3) BISCAYE, P.E., Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans, Geol. Soc. Amer. Bull., v. 76, p. 803-832, (1965)

(4) BISCAYE, P.E., Distinction between kaolinite and chlorite in recent sediments by x-ray diffraction, Amer. Mineralogist, v. 49, p. 1281-1289, (1964).

(5) SAYLES, F.L., and MANGELSDORF, D.C., The equilibrium of clay minerals with seawater: exchange reactions, Geochem., Cosmochim. Acta, v.41, p. 951-960, (1977).

(6) U.S. ARMY CORPS OF ENGINEERS, Laboratory soils testing, EM-110-2-1906, Appendix II, Washington, D.C., (1970).

(7) EMERY, K.O., Atlantic continental shelf and slope of the United States, Geol., Survey Prof., Paper 529 A: 23 p., (1966).

(8) SHEPARD, F.P., Nomenclature based on sand-silt-clay ratios, Jour. of Sed. Petrology, v. 24, p. 151-158, (1954).

(9) STANLEY, J.S., and WEAR, C.M., The "mud line": an erosion-deposition boundary on the upper continental slope, Marine Geology, v.28, M-19-M-29, (1978).

(10) EMERY, K.O., and UCHUPI, E., Western North Atlantic Ocean: topography, rock, structure, water, life and sediments, Amer. Assoc. Petroleum Geologists Memoir. 17, 532 p., (1972).

(11) FRIEDMAN, G.M., On sorting, sorting coefficients, and the log normality of the grain-size distribution of sandstones, Jour. Geology, v.70, p. 737-752, (1962).

(12) HATHAWAY, J.C., Regional clay mineral facies in the estuaries and continental margin of the United States east coast; in Nelson editor, Environmental framework of Coastal Plain estuaries, Geol. Soc. of America, Memoir 133, p. 331-358, (1972).

(13) TUREKIAN, K.K., Oceans, Prentice Hall Inc., 120 p., (1971).

(14) DAYAL, R.S., OAKLEY, S., and DUEDALL, I.W., Sediment geochemical studies of the Atlantic 2800 meter nuclear waste disposal site, personal communication, in press.

(15) AMES, L.L., and Rai, D., Radionuclide Interractions with soil and Rock Media, Volume 1, EPA, 520/6-78-007, p. 174-186, (1978).

(16) HEATH, R.C., Barriers to radioactive waste migration, Oceanus, v. 20, p. 26-30, (1977).

(17) BONDIETTI, E.A., and FRANCIS, C.W., Chemistry of Technetium and Neptunium in contact with unweathered igneous rock; science underlying radioactive waste management. Materials Research Science Meeting, Boston, Mass. 28 Nov-1 Dec, p. 57, (1978).

(18) SEITZ, M.G., et al., Migratory properties of some nuclear waste elements in geologic media, Nuclear Technology, v. 44, July (1979).

(19) HUBERT, J.F., and NEAL, W.F., Mineral composition and disposal patterns of deep-sea sands in the Western North Atlantic Province, Bull. Geol., Soc., Am., v. 78, p. 749-772, (1967).

(20) KELLER, G., and SHEPARD F.P., Currents and sedimentation processes in submarine canyons off the northeast United States. in: D.J. Stanley and G. Kelling (Editors), Sedimentation in submarine canyons, fans, and trenches. Dowden, Hutchinson and Ross, Stroudsburg, Pa, pp. 15-32, (1978).

(21) STANLEY, D.J., SHENG, H., and PEDRAZA, C.P., Lower continental rise east of the Middle Atlantic States: predominant sediment dispersal perpendicular to isobaths., Geol. Soc. Americal Bull, v. 82, p. 1831-1840, (1971).

(22) McMASTER, R.L., and GARRISON, L.E., Mineralogy and origin of southern New England shelf sediments, Jour. Sed., Petrology, v. 36. n. 4, p. 1131-1142, (1966).

(23) ROSS, D.A., Atlantic shelf and slope of the U.S. ;heavy minerals of the continental margin from southern Nova Scotia to northern New Jersey, USGS Prof. Paper 529-G, 40 p., (1970).

(24) NEIHEISEL, J., 1973, Source of detrital heavy minerals in Atlantic Coastal Plain estuaries: Georgia Institute of Technology, Ph.D. dissert., 181 p., (1973).

(25) ALEXANDER, A.E., A petrographic study of some continental shelf sediments: Jour Sed. Petrology, v. 4, p. 12-22, (1934).

(26) McMASTER, R.L., Petrography and genesis of the New Jersey beach sands, New Jersey Dept. of Conservation and Economic Development, Geological Survey Bull., 63, 239 p., (1954).

(27) McCARTHEY, G.R., Coastal sands of the eastern United States, Amer. Jour. of Science, v. 22, p. 35-50, (1931).

(28) KELLING, G., SHENG, H., and STANLEY, D.J., Mineralogic composition of sand-sized sediment on the outer margin off the Mid-Atlantic States: assessment of the influence of the ancestral Hudson and other fluvial systems, Geol. Soc. of America Bull., v. 86, p. 853-862, (1975).

(29) SHEPARD, F.P., and COHEE, G.V., Continental shelf sediment off the Mid-Atlantic States, Geol. Soc. Americal Bull., v.47, p. 441-458, (1936).

(30) U.S. ARMY CORPS OF ENGINEERS, Shore of New Jersey-Barnegat Inlet to Cape May Canal, beach erosion control study, House Document 208, 86th Congress, 1st session, Philadelphia, Pa., 107p., (1959).

(31) U.S. ARMY CORPS OF ENGINEERS, Delaware coast, beach erosion control and hurricane protection, Senate Doc. 90, 90th Congress, 2nd Session, Philadelphia, Pa, 110p., (1968).

(32) TWICHELL, D.C., KNEBEL, H.J., and FOLGER, D.W., Delaware River, Evidence for its former extension to Wilmington Submarine Canyon: Science, v. 195, p 483-485, (1977).

* U.S. GOVERNMENT PRINTING OFFICE: 1979 -281-147/142